2

COATINGS FOR SELECTIVE MICROWAVE ABSORPTION.

REPORT FOR PHASE I OF SBIR CONTRACT
NO: DAAL02-91-C-0028

BY

1991

NUKA V. REDDY
APPLIED POLYMER SYSTEMS, INC.,
P.O.BOX 4040
COLLEGE POINT NY 11356.

CONTENTS.

Background:

A fundamental consideration in the design of military communication systems today is combat survivability in a highly hostile environment. In the absence of such survivability potential, the ability of most critical communication systems to fulfil its mission is jeopardized. Communication survivability depends upon many factors;

protection from EMI/RFI/EMP

protection from temperature/weather

protection from high power microwave (HPM) during EW

protection from ordinary ground based or air-borne radar

This research attempts to find a solution for one such threat namely protection from HPM.

The main objectives of this research work is to develope a low cost microwave absorptive materials(MAM) to protect electronic components, devices, and equipment from HPM. The objectives are to identify, characterize, and evaluate sample absorptive materials under phase I of SBIR contract DAAL02-91-C-0028. Another requirement of this research work was to develope a product that can be formulated in such a way so that it can be applied very easily on a variety of components such as printed circuit boards, coaxial wave guide low-pass/high pass or pass band filters, radomes and antennas. In general these materials should have a greater than 20 dB out of band absorption and less than 0.5 dB insertion loss, and absorption frequency profile that increases rapidly with

frequency. Finally the cost should be minimum.

The proposed work was formulated into the following tasks to carry out during the 6 months period assigned. Those tasks were

1) To survey and establish a data base for currently available microwave ferromagnetic and ferrimagnetic materials from various literature sources in order to identify suitable materials with appropriate characteristics to achieve broad out-of-band attenuation and selective in-band transmission.

2) To select a suitable polymer vehicle system and explore the possibility of formulating a coating or paint

3) To formulate representative ferrite materials into coatings in easily applicable forms

4) To formulate specifically a coating with the following specific design goals;

$S21 < 0.5$ dB from 10 MHz to 100 MHz

$S21 > 20$ dB above 0.5 GHz.

INTRODUCTION:

Since this work uses ferromagnetic and ferrimagnetic materials for dissipation of the effects of HPM, it is appropriate to give a brief review of theoretical principles involved in the interaction of electromagnetic radiation in microwave region with ferromagnetic and ferrimagnetic materials.

There is a difference between ferromagnetic materials and ferrimagnetic materials. Ferrimagnetic materials are also called ferrites. Therefore these two names will be used synonymously in this report. In ferrites, the magnetic ions are distributed over at least two interpenetrating sublattices, whereas ferromagnetic materials have same lattice structure. All of the magnetic moments with in each sublattice are aligned in ferrites, but the sub-lattices are oppositely directed[1]. A microwave ferrite is defined as a high frequency magnetic material useful between 100 MHz to 500 GHz[2] for various purposes including microwave absorption. Ferrites have an additional advantage over other types of magnetic materials. They have high electrical resistivity, and resultant low eddy current losses over a wide frequency range. Additional characteristics such as high permeability and time/temperature stability have expanded ferrite uses into quality filter circuits, high frequency transformers, adjustable inductors, delay lines, and other high frequency electronic circuitry. As the high frequency performance of other circuit components continues to be improved, ferrites are routinely designed into magnetic circuits for both low level and power

applications.

The electronic and crystal structure of ferromagnetic materials such as iron, nickel and origin of their magnetic properties is a thoroughly researched and well established subject and is given in various standard references[3]. Further, since our aim here is to explore the possibility of using ferrimagnetic materials for selective absorption, it is appropriate to give more emphasis to ferrimagnetic materials.

The chemical structure of ferrites is $(MO)(Fe_2O_3)$, where MO is a metal oxide of a divalent metal such as Fe, Mn, Co, Ni, Mg, Zn, Cd,. They are prepared by thoroughly mixing the iron oxide and the metallic oxide Mo. The mixture is then fired at a higher temperature which is less than melting point of either oxide. At higher temperatures, oxides sinter together into a spinal crystal structure[4]. The spinal crystal structure consists of layers of oxygen atoms, with the smaller metal atoms in the interstices of oxygen atoms. Usually the iron atom is surrounded by 6 oxygen atoms, in octahedral configuration and metal atom in a tetrahedral configuration. The distribution of ions between two types of sites is determined by a delicate balance of contributions, such as the magnitude of the ionic radii, their electronic configuration and electrostatic energy of the lattice. The important atomic property that contributes to the observed magnetic properties is electronic spin quantum number. The unpaired spins of the metal atom, contribute to the magnetic moment and vector sum of the resulting magnetic moments is the observed

magnetic moment of a given atom. The magnetic moment of a given ion is affected by the crystal field exerted by oxygen atoms on the ion, and the net magnetic moment of unit cell is sum of magnetic moments in the unit cell. Iron atoms may be in tetrahedral or octahedral field, where as metal atoms are in the octahedral field. In this type of structure, iron atoms have a tendency to reverse their spins in the A and b sites, leaving only the metal ions to contribute to the magnetization of the ferrite. Conversely, by adjusting the ratio of Fe/metal atoms in the ferrite, it is possible to design a material with any desired saturation magnetization. Saturation magnetization is important because the oscillating magnetic vector of propagating electromagnetic radiation in the microwave region can couple to spinning electrons in ferrites, and therefore the degree of coupling depends upon the magnitude and direction of electron spin. Saturation magnetization as explained above is the net magnetization due to all electrons. Therefore degree of coupling depends upon saturation magnetization.

Essentially, each unit cell of ferrite acts as a tiny magnet with finite magnetic moment and all these magnetic moments add up provided the direction of all these magnetic moments is same. The region of the crystal where this condition satisfied is called domain. The vector sum of all these domain magnetic moments is the observed saturation magnetization of a given material. Although these randomly oriented domains may be directed in the field direction under applied field, they revert back to their equilibrium position once the applied field is

removed. However, this is not the case in ferromagnetic materials like iron, Ni, where there is a restraining force that tends to keep electrons near each other spinning in the same direction.

The mechanism of interaction or coupling of MW radiation with ferrite materials in the applied magnetic field is as follows; When a solid ferrite material is placed in a magnetic field, it will have a resonance frequency given by $w = \sqrt{}\ H_i$, ...(1)

where w is the mid band resonance frequency, √ is the gyromagnetic ratio, and H_i is the internal magnetic field in presence of H_a, the applied magnetic field. In other words not only electrons spin about their own axis, but also precess about the stationary magnetic field H_i at a frequency given by equation 1, if damping losses are neglected. If MW radiation corresponding to the resonance frequency and polarization is incident upon these spins, the oscillating magnetic vector of incident radiation couple with spins. The energy exchange manifests by changing the angle between the spin axis of the electrons and the H_i. The coupling is expressed as loss of energy with units of dB. Usually the loss is not sharp and has a range of frequency called line width. The smaller the line width the sharper the peak or vice versa. Further H_i is a function of the geometry of monolithic ferrite material.

However, this mechanism may not be useful if the materials are ferrimagnetic powders. In case of powders, the orientation of various crystallites is random and therefore, unless extremely high field is applied, the H_i is near

zero. If there is no applied field, and the only field is that derived from HPMW, then the mechanism of interaction between ferrimagnetic materials and suitable frequency in the MW region may be different and is not worked out clearly in the literature. A brief review of that is given as follows

Although it is possible to couple EM radiation with electronic energy levels in an atom, ferrite materials exhibit high insulating and passive dielectric properties. Therefore the only alternative for propagating electromagnetic waves could be to couple with magnetic properties.

Frequency dependent magnetic field (h) from applied radiation induces R.F. magnetic induction (b) inside the ferrite material. R.F. magnetic induction dependent upon the state of prior magnetization and the frequency of applied R.F. radiation. The scaler permeability μ_i = b/h, and is a complex quantity represented by $\mu_i = \mu_i' - \mu_i''$, where

μ_i' = real part of permeability

μ_i'' = imaginary part of permeability.

The energy dissipation from time varying (oscillating) magnetic field is expressed as loss factor and is tan $\delta = \mu_i''/\mu_i'$.

As explained before, ferrimagnetic materials exhibit magnetic property by spatial ordering of electron spin orientation of electrons from magnetic ions in the crystal. Radiation in the microwave region under proper conditions, may spontaneously realign electron spins during magnetization. In a microscopically demagnetized sample, the domains are arranged in

haphazard orientation. Low frequency microwave radiation typically attenuated by domain wall movement and high frequency microwave radiation by rotational resonance effects.

Another mechanism of M.W. absorption by ferromagnetic materials is nonlinear absorption as a function of radiation power level. At milliwatt power level the insertion or absorption loss can be small, but at higher power level a sudden increase in absorption is observed beyond that and continue until saturation is achieved[5]. The generally accepted mechanism for this observation is due to excitation of spin waves where the microwave field exceeds a critical value. The critical field is dependent upon many factors such as geometry, magnetization, R.F. power level, main resonance line widths, gyromagnetic ratio and operating frequency. Another factor relevant for our discussion is that there exists a spectrum of spin waves in any material with varying energy levels excitable by different critical field levels. Therefore, the absorption will increase as M.W. power increases as more spins are excited. However, in polycrystalline powders the grain boundaries provide sufficient discontinuity to break up spin waves.

To summarize there are several mechanisms at play in ferrite materials to absorb energy from HPMW. One of the thrust of this work to first identify the ferrite materials available and what type of magnetic properties they have so that a determination can be made as to their applicability for this work or for any other work.Therefore, it is essential that

a data base should be established for ferrite materials.

There are several difficulties to maintain a data base for these materials. In several cases the composition is itself not defined, nor their electrical and magnetic properties. In the cases where the composition is defined and their magnetic properties are defined, the properties are not easy to tabulate because there is no standard methods of measurement.

We have summarized the data available in appendix I.

At present there are several polymer coatings for microwave or radar absorption materials are available commercially. Most of these are sold for the general purpose of suppressing electromagnetic interference and radio frequency interference.

Emerson & Cuming sells high loss epoxy formulations which can be brushed on the surfaces under the trade name Eccosorb1 Eccosorb coatings will attenuate surface currents from 50 MHz through microwave frequencies. These coatings are useful in reducing Q of cavities, acting as attenuators in transmission lines, modifying antenna patterns by being applied to radiating elements and reducing radar cross section of complex objects. However these coatings are not suitable for reducing specular reflectivity, but multiple reflection component and surface wave current component can be attenuated by these coatings. They have good mechanical properties and can adhere well to several

surfaces. Although the composition of material is secret, it believed to be having ferromagnetic powders basically iron powder. Spectrum Materials, Inc.,[6] has a material, Wavecoat™, which is a coating for control of surface currents and reflections in RF and microwave applications. It contains a highly permeable filler and yields a large loss tangent to signals over a broad range of microwave frequencies. It may be applied directly to any surface where attenuation of reflected and/or secondary Rf signal is required. WaveCoat is a two-part silicone rubber based or one part polyurethane based coating. waveCoat reduces the level of signals launched by discontinuities by attenuating the fields associated with the travelling wave before they reach the discontinuity. In the same manner, cavity resonances are damped by this because the associated wall currents are attenuated and the overall Q is lowered.

METHODS AND MATERIALS:

Phase I objective is to prove the feasibility of the concept or idea selected, and identifying variables involved in obtaining a result to prove the feasibility, we decided early on to select one binder applicable for all coating system. In coating formulation terminology, a binder or vehicle is a material usually an organic polymer. A pigment usually an inorganic substance in a finely divided powder form. A coating is a combination of binder and pigment mixed uniformly in presence of a solvent and applied to the surface to be coated. After the evaporation of solvent, which we call drying, the pigment is held by the binder matrix in a uniformly dispersed state. In general, the composite of a pigment and a binder with necessary dispersing agents is called paint or coating. There are numerous binders available commercially such as latexes, epoxies, urethanes, silicones, etc., and so are pigments. Some important pigments are titanium dioxide, calcium carbonate, barium hydroxide, chrome yellow etc.,

Based upon the earlier work[7], we have identified a commercial material hypalon® (Chlorosulfonated polyethylene sold by DuPont Company) for binder. This material is economical, readily available, and has several good solvents. We have consistently used toluene to dissolve Hypalon. Although toluene is a flammable solvent under proper conditions it can be used safely. The point to emphasize is this same binder and solvent can be used for other powders including any ferrite powders that

has the potential to absorb MW radiation in specific frequencies in order to obtain a window.

All ferromagnetic and ferrimagnetic materials used in this work are available commercially. We have obtained iron, nickel and copper powders from Alfa industries. lithium and zinc ferrites were obtained from Trans Tech industries. Hypalon is provided by DuPont company. All other chemical are reagent grade and are obtained from Aldrich chemical company.

However, several ferrite powders that we wanted to use could not be obtained commercially. Although their synthesis is straight forward from readily available oxides, due to time and equipment constraints we could not made and test those materials in Phase I. If we have done that, additional data would have been available to present here. Therefore, preparation and testing of several ferrites is one of the objective of phase II work.

A dielectric strip of 50 Ω 2 cm X 7 cm was cut from RT/Duroid 5880 microwave laminate made by Rogers Corporation. The dielectric constant of this laminate is 2.20 ± 0.02 at 10 GHz and thickness of 0.031" ± 0.001". The width of the copper line is 0.1 cm and is connected to SMA female bulkhead connectors obtained from Pasternack Enterprises, CA. The laminate as obtained from Rogers corporation is cladded both sides by copper. In order to obtain the copper line we applied etch resistant coating and stripped copper in ferric chloride solution. When examined under microscope we did not notice any

discontinuities suggesting that this procedure is reliable.

Preparation of Coatings:

The preparation of coating is simple and straight forward. Required amount of Hypalon was first dissolved in toluene at room temperature. This solution was stable for storage for the entire length of the project. We have used a 10% solution. If it is applied as such we can get a good film with excellent adhesion on most substrates including the dielectric substrate mentioned above. As the printed circuit board materials used in computers more or less resembles the experimental laminate, the results obtained can be realistically extrapolated to the intended application.

Required amounts of ferrites or ferromagnetic materials are then added to known amount of Hypalon solution and mixed mechanically. They were made more uniform by adding surface active agents such as FC-120^R(3M). A through mixing is usually sufficient to make it uniform slurry for proper application. These slurries however were phase separated into solvent and solid phase on standing overnight. Our qualitative observation revealed that the solid phase contains all the pigment and polymer. Further mechanical mixing of these two phases is usually enough to get all into one uniform phase before application. We can confidently say that storage stable formulation can be developed by optimising any of the ferrimagnetic material containing paint by adding appropriate stabilizers and surfactants.

The coating was applied with a

spatula along the copper strip to the desired thickness and allowed to dry overnight. We let solvent to evaporate at room temperature although it may take time up to 24 hours. There is no need to dry under heating and this is an advantage because the dielectric laminate may be damaged if subjected to the temperature. Furthermore, in field applications, these circuit boards can not be subjected to high temperature in any case. Further, additional methods coating such as dip coating or spray coating can also be used if the coating has to be on both the surfaces of the board. These paints can also be applied brush if necessary, although we did not use this method.

Attenuation measurements:

The attenuation measurements of the painted microstrip circuit was measured by time domain reflectometry and frequency domain scattering measurements. The measurements were done at State University of New York. Stony Brook Microwave Laboratory. The attenuation was measured between 50 MHz - 17.5 GHz by HP 8510 A automatic network analyzer with synthesized sweep generator. The two probes were connected to 2 ports of microstrip circuit and scanned as a function of frequency and an automatic data processing plotter was used to plot the attenuation profile. The figures shown in appendix were copies of those plats for various attenuation measurements.

RESULTS AND DISCUSSION:

This part describes the results we obtained and their interpretation. As explained before we have concentrated in the low frequency region, as required by the contract, to obtain a sharp increase in attenuation around 100 MHz with negligible attenuation up to that frequency. Therefore, we concentrated all our time and effort to develope a coating with required ferromagnetic and/or ferrimagnetic materials and which has desirable attenuation properties. As explained in the methods and materials section, the binder for this coating material is chlorosulfonated polyethylene in toluene and MEK. This is the base paint and into which we have added iron, nickel, copper and ferrite powders either alone or in combination. Other pigments used were lithium zinc ferrite, silver coated glass spheres. The completely dispersed coating is then applied to 50 Ω standard dielectric strip circuit as explained in the experimental section.

Figure 1 is the background attenuation of unpigmented paint containing a 10% Hypalon, in toluene. As can be seen in this figure, the attenuation is less than 1 dB in the region of 50 Hz to 18 GHz, specifically the attenuation is less than 0.5 dB in the region 50 MHz to 2 GHz. This shows that there is no inherent insertion loss or attenuation due to binder or solvent and, therefore in coatings, any attenuation over this background has to be due to the added material namely a ferromagnetic or ferrimagnetic substance.

Figure 2 shows the attenuation

profile of one of the paint we formulated. As can be seen from this figure, there is no attenuation up to 500 MHz, and after 500 MHz it gradually decreases to 40 dB by 5 MHz and stays that way all the way to 18 GHz. This is the major reproducible result we have got from this work. This is a promising coating formulae and an optimization of this formulae by adding another ferromagnetic or ferrite material may provide a sharp drop of insertion loss at 100 MHz. However, there is no theoretical basis to predict which ferrite or ferromagnetic material can provide such a desirable result. This work has to be approached on semi-empirical basis and has to be determined using different materials in combination. Such an effort requires a substantial investment of resources than can be done here in phase I.

Fig 3. is the attenuation profile of a paint Eccosorb 269 E made by Emerson & Cuming . It is a two component epoxy paint with iron powder and applied to the microstrip according to the manufacturers directions. This, has a gradual attenuation up to 15 GHz and then there is a sharp peak at 16 MHz. The profile of this absorption shows that such sharp peaks can be used to design windows for high insertion loss at that frequency.

Figure 4. is the attenuation profile of a paint with standard vehicle and iron powder. Here also there is no attenuation of more than 5 dB from 0 to 18 GHz. This clearly shows that nickel is the contributing factor and the magnetic

moment of nickel and iron are interacting in a fashion to obtain that result.

Fig 5. is due to a paint system that contain powder and lithium ferrite (Li FeO_4), a ferrimagnetic substance. Lithium ferrite was selected under the assumption that a domain wall movement may contribute to the low frequency absorption. Its susceptibility is not known. However, it does not have any effect on attenuation in the regions we are interested here.

Figure 6 is the attenuation profile of nickel ferrite, with a saturation magnetization around 5000 gauss in Hypalon. Again we see that there is no absorption of significance in low frequency region.

Figure 7 is the attenuation profile of iron and nickel powder with added nickel ferrite. Surprisingly, here the attenuation decreased rather than increased. There is no theoretical justification for this result as far as we know. However, this may change if we use another ferrite with different composition and structure. We are not analyzing the mechanisms here but this specific result reveals that several mechanisms are at interplay for the interaction of radiation and the magnetic materials used in this paint.

Our work carried out so far proves that a paint system containing iron and nickel powder satisfy the

assigned specifications to a large extent. One conclusion we can draw from this work is that nickel, a ferromagnetic material, is the attenuator for low frequency region. However, it is not optimised in phase I. If it is optimised in phase II it will satisfy the given specification. Furthermore, we have basically established a general method of making a paint incorporating ferrite or ferromagnetic material. This methodology, namely first making a base paint then adding whatever magnetic material required is very convenient because in the field one can vary the composition in the coating and obtain the desired insertion loss on a short notice depending upon the conditions. This binder system as a matter of fact can be used for any powder to make a paint. Therefore, in that respect the ground work has been done for future work.

In the development of any communication low pass or high pass windows, it is essential that the magnetic material should have a clearly defined absorption property in a given frequency range. These type of materials when mixed with binder may provide same or decreased attenuation in the characteristic region. We were unable to make a paint now because of the unavailability of the materials. The only way we can obtain this material is by custom manufacturing which is prohibitively expensive or making by our selves. We did not have the required high temperature oven to do this synthesis of this material.

During Phase II we will do this type of work. With close consultation with the agency, we have to

identify the frequency regions where a low pass or high pass band is required and a specification will agreed for this. This is similar to the final task in this work. Then we will identify the required materials from different sources and either procure them or will synthesize in our laboratory. The ovens and furnaces required for this synthesis work are not expensive and are readily available. Their total cost is estimated to be around $20,000.00. The raw materials for synthesis of any ferrite material of any compositions are mostly oxides of transition and non transition metal oxides, and are readily available from various vendors. The usual time period for this synthesis is around 2 days. Therefore if we set up this furnace systems, we can have a complete control of the materials that we can make and the particle size and composition required.

Finally this work conclusively proved that it is possible to develop a easily applicable and low cost paint system that can have a desirable attenuation of HPM.

APPENDIX A.

The area of ferrimagnetic oxides is a very well researched area and there are numerous references for the synthesis and characterization of oxides. However, all oxides are not applicable in microwave region. The research findings of important workers in the field of ferrites is reported periodically in international conference on ferrites. So far there were four conferences. They are

1) Proceedings of International conference on ferrites, held in Kyoto on July 6, 1970. Ed. Y. Hoshino, S. Lida and M. Sugimoto. University Park press. Baltimore.
2) Proceedings of 2 ICF held in Bellevue (France) 14-17 Sep 1976. Jour. De. Physique. Colloque. 38, C-1 to C-7.
3) Proceedings of ICF 3 held on Sep 29, 1980. Ed. H. Watanabe, S. Iida, M. Sugimoto. Center for Academic publications. Japan
4) Proceedings of the 4th ICF held in San Francisco. Oct 31, 1984. Ed. Franklin F.Y. Wang. Advances in Ceramics Vol 15 and 16. American Ceramic society Inc., Columbus OH.

There are several reports in these conference proceedings where the synthesis, characterization, and magnetic properties of various ferrite were discussed. The diversity of properties and the methods used are too numerous to classify under any standard classification. However, for any future work these above references are invaluable. These proceedings also contain few references for their application in the M.W region.

One has to identify and include the following ferrite materials magnetic characterizations to develope a data base. However, for some reported ferrite material, not all the properties are available. The important properties one should include

(a)composition

(b)density

(c)Linde g, factor

(d)g-eff.

(e)Line width
H Oe.

(f)Dielectric cont.
ϵ'

(g)Dielectric loss
tangent tan δ.

(h)Curie temp. °C.

(i)Spin wave line
width.

(j)Remnant Induction
B (gauss)

(k)Coercive Force
(H_c) Oe

(l)Initial Permeability
μ_o

Since our objective was to develope a coating containing ferrite powders, its natural that we will limit the ferrite materials description to only powders. There are not that many powder materials that were characterized. Some of the materials described here are taken from trade lit rature and others are from scientific literature.

COMMERCIAL PRODUCTS AVAILABILITY AND THEIR SUPPLIERS.

A. Trans-Tech Inc., 5520 Adamstown Rd. Adamstown, MD 21710
Tel: (301) 695-9400.

This company markets various microwave materials, including microwave ferrites, garnets, microwave dielectrics. It supplies magnesium ferrites with saturation magnetization(M) up to 3000 gauss with particle size diameter of 50- 200 μ. Similarly it supplies nickel ferrites with M up to 5000 gauss, lithium ferrites up to 4000 gauss. The ferrite materials for this work were obtained from this company. Their powders mix well with the resins we used. This is the only company that provides data about characteristics for all the compounds they list. The ferrite powders are available in different particle sizes.

B. Dexter corporation; Magnetic materials Division.

This company markets linear ferrites made by siemens, magnetics, Fair-Rite, Kristinel, and Hitachi basically for cores of any inductance value in a wide range of sizes and materials. They are not suppliers of powders especially in micron size. However, their custom synthesis facility will be able to formulate any ferrite powder.

C. Xtalonix; 1215 Chesapeake Av. Columbus, OH 43212.

Xtalonix sells magnesium and nickel ferrites. Magnesium ferrites are available from saturation magnetization of 750 gauss to 3000 gauss and nickel ferrites are available from 500 to 5000 gauss. All other important properties for these materials are available from this company.

D. Ampex Ceramic materials Operation; 728 San Aleso Av. Sunnyvale CA 94086-1411.

Ampex markets lithium ferrites in triangles, discs, composite assemblies, rectanguiar round rod and tubes, plus bulk shapes such as bars, blocks, slabs, and cylinders and powders. Their saturation magnetization range from 900 to 4000 gauss. They also supply magnesium- manganese microwave ferrites although to a limited extent. Their main product line is garnets and inductive ferrites for magnetic recording.

E. Magnetic materials Group PLC; 1. Swallow Court. Swallowfields. Welwyn Garden City. Hertfordsshire AL7 1SB. England.

This company markets various hard and soft ferrites mainly for cores. But on special order they also supply ferrite powders. Specifically they provide magnesium-zinc ferrite and nickel-zinc ferrites.

E. Philips Components; sellls through their distributors.

Most of ferrite products sold by Philips are in components form. The main product line is cores, but shielding beads, wired beads, wide-band chokes, rods, tubes are also available. They do not market any powders per se, although

they must be using them to make above products.

G. Sumitomo Corporation of America; 345 Park Av. NY NY 10154; 212-207-0700.

Sumitomo markets soft ferrites in components form essentially for cores.

H. FDK America Inc.; 2880 Zanker Rd. #102. San Jose, Ca 95134; 408-432-8331.

FDK offers many types of low loss high performance ferrites for microwave applications. These MW ferrite products divided into spinal and garnet type providing large selection of saturation magnetization values to match a wide variety of frequencies from VHF and UHF to mm waves. These ferrites go into circulators, isolators, phase shifters, satellite communications products, and radar applications. FDK also does not market powders per se.

I. Tokin America Inc., 155 Nicholson Lane. San Jose, CA 95134. 408-432-8020.

Tokin sells Mn-Zn and Li-Zn ferrite materials of varying properties for cores. Specifically, Mn-Zn ferrite materials with high permeability to be used in linear low level transformers, wide band and pulsed transformers, EMI fillers, and a host of other applications. Essentially all of the products

of this company are in the cores. Spinal ferrites useful for X and K- band applications are also sold by this company.

J. Magnetics;Division of Spang & Company. 900 E Butler Road. P.O.Box 391. Butler PA 16003. Tel: (412) 282-8282.

Magnetics basically sells ferrite cores. Their ferrite products are used in filter inductors, narrow band transformers, power transformers, broad band transformers, pulse transformers, converter and inverter transformers, recording heads, noise filters, etc., The custom component division may also fabricate powders of specific composition.

REFERENCES:

1. W,H, Von Aulok; " Handbook of Microwave Ferrite Materials", Academic Press, NY 1965. Section I.

2. J. Nicolas in " Ferromagnetic materials" Vol 2. Chap 4. Eds. E.P. Wohlfarth.; North Holland Publishing Co., 1980.

3.(a) " A basic introduction to the properties and uses of microwave ferrite materials." Trans- Tech, Inc., Adamstown, MD.,
(b) A.S. Chakravarty.; " Introduction to magnetic properties of solids". John Wiley & Sons. NY 1980.
(c) Klaus Schröder.;" Electrical, magnetic and thermal properties of solid materials." Marcel Dekker Inc., NY 1978.
(d) S.V. Vonsorskii.; "Ferromagnetic Resonance" Pergamon Press. Oxford. 1966
(e) E.P.Wholfarth.; " Ferromagnetic materials. Vol 2. North Holland Publishing co., Amsterdam. Chap 4. Microwave Ferrites. by J. Nicolas.
(f) David Jiles.; " Introduction to magnetism and magnetic materials." Chapman & Hall. London 1991.
(g) Soshin Chikazumi and Stanley H. Charap.; " Physics of Magnetism." John Wiley & Sons. 1964.

4. D.J. Craik.; " Magnetic Oxides". Part 2. Jhon Wiley & Sons. NY. 1975.

5. 1. N. Bloembergen, and S. Wang; " Relaxation effects in para and ferromagnetic resonance." Phys. Rev.; 93 (1954) 72.
2. R.W. Damon. " Relaxation effects in ferromagnetic resonance." Rev. Mod. Phys.; 25, (1953) 239.
3. H. Suhl. " The theory of ferromagnetic resonance at high signal powers.; J. Phys. Chem. Solids.; 1, (1975) 209.
4. E.E. Schlomann, J.J. Green and D. Milano.; "Recent developments in ferromagnetic resonance at high power levels.; J. Appl. Phys.; 31, (1960) 3865.

6. Spectrum Materials, Inc., 3010-E Business Park Dr. Norcross, Ga 30071. Tel:(404) 840-0107.

7. (a) Takeshi Ishino, Kenichi Ichihara, Takashi Watanabe.; Jpn. Pat No: 79, 41,495. CAS 91:12873 d.
(b) Takeshi Ishino, Hiroshi Yamashita, Takashi Watanabe.; Jpn. Pat No. 79, 110,497. CAS 91: 221545n.

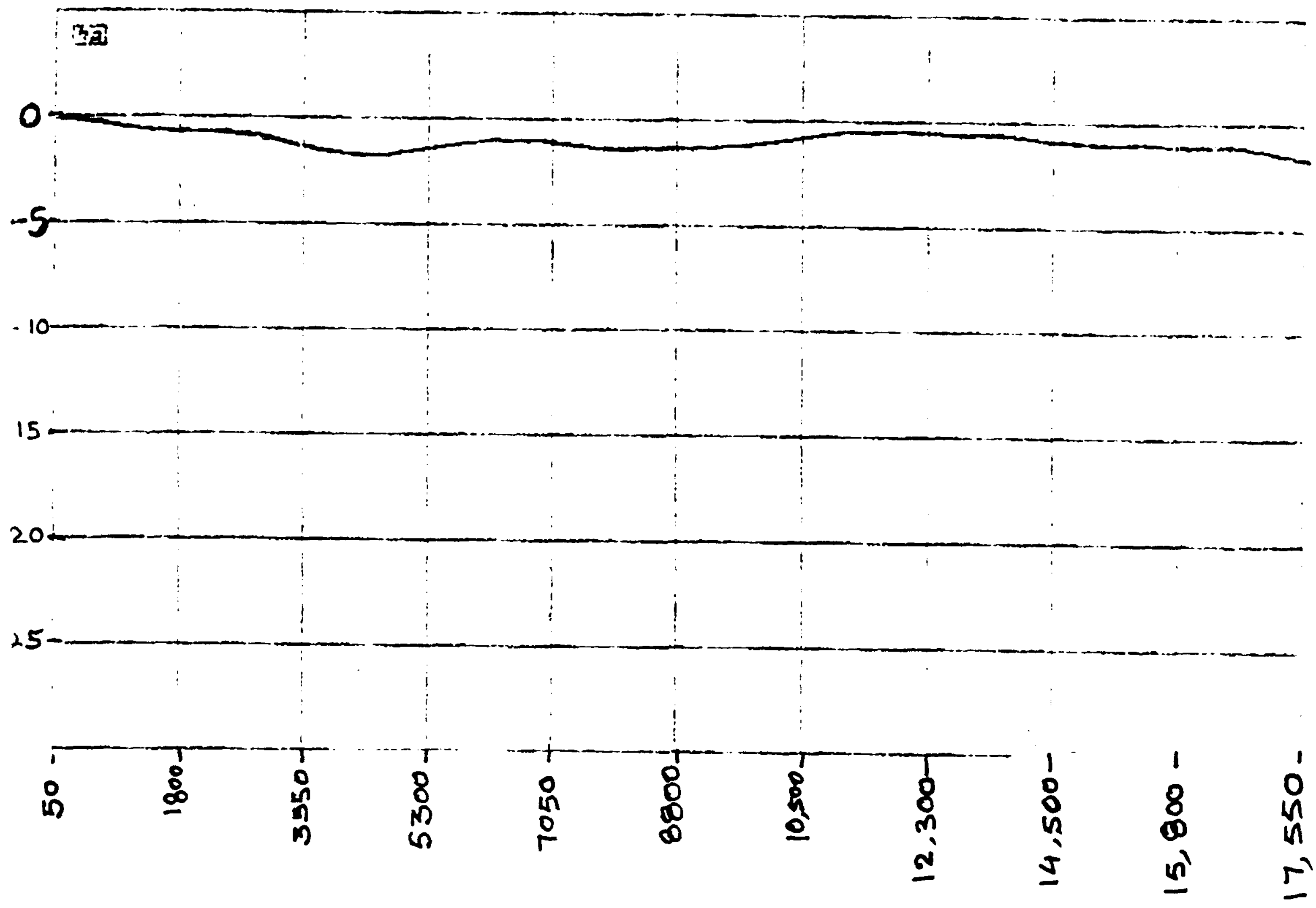

Figure 1. Attenuation profile of the binder. 10% Hypalon solution in toluene.

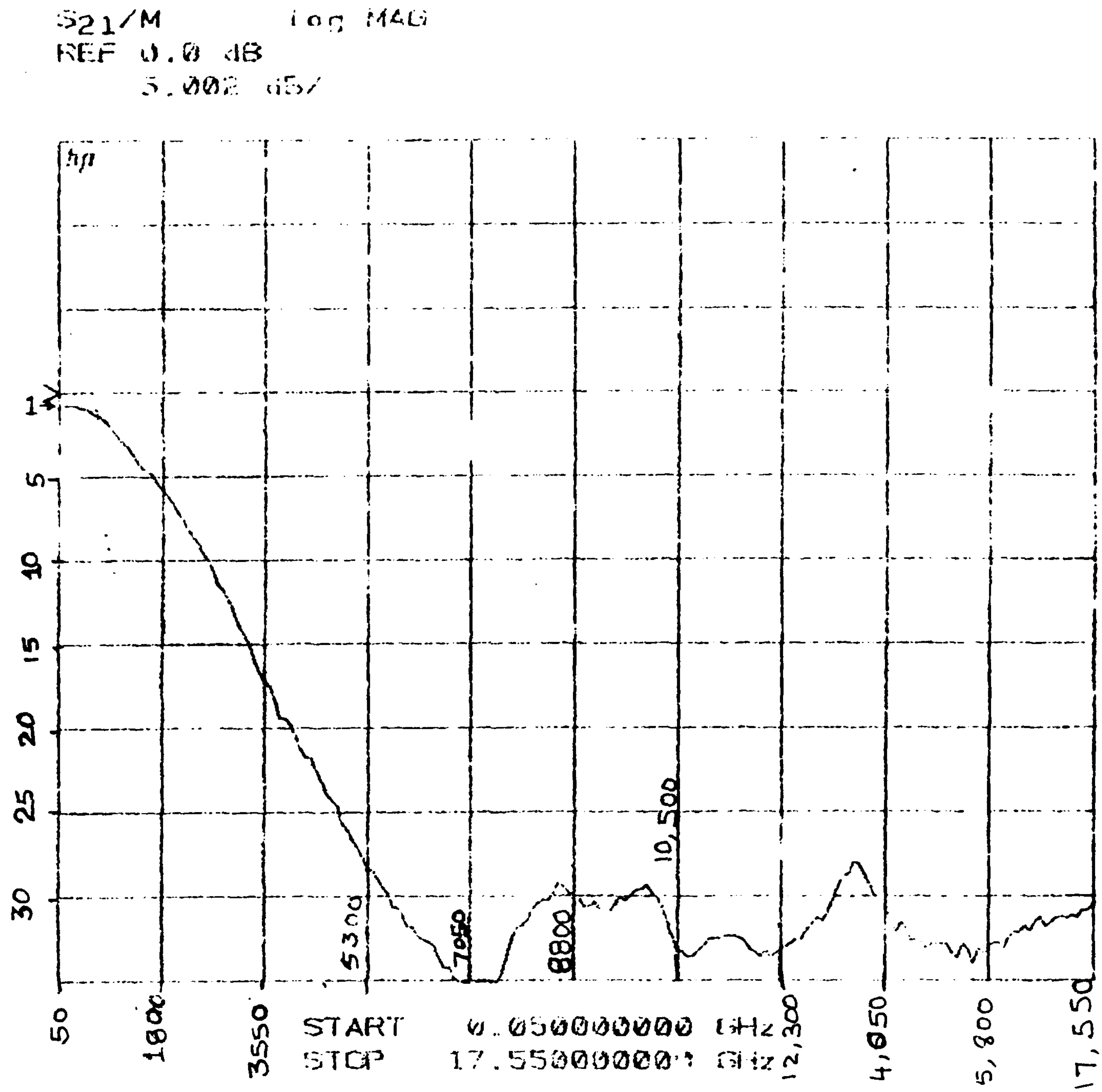

Figure 2. Attenuation measurements of a paint. 10 gms of 10% Hypalon, 5 gm of iron powder, 5 gms of nickel powder, 1 gm of methyl ethyl ketone.

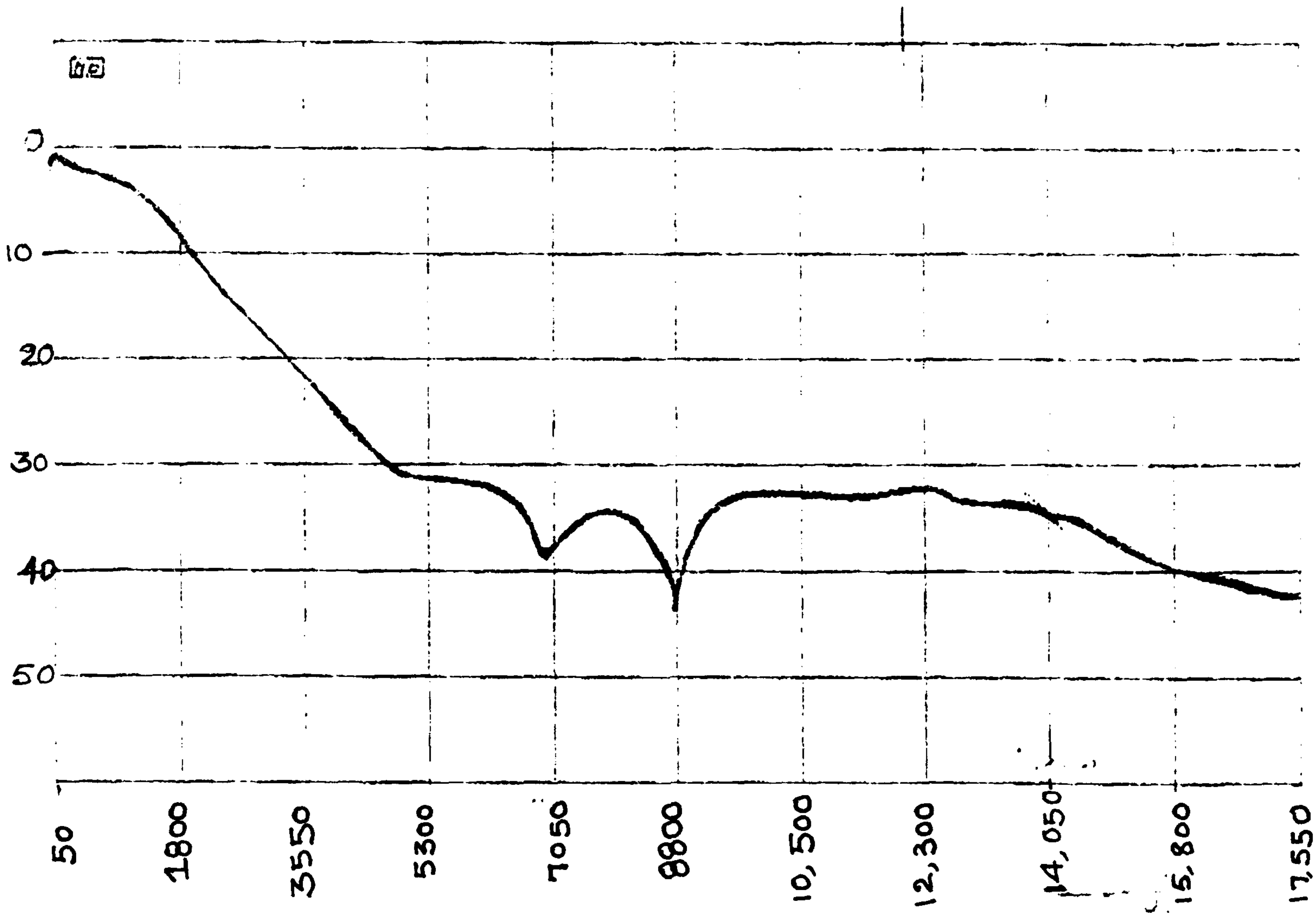

Figure 3. Attenuation measurements of Eccosorb 269 E manufactured by Emerson & Cuming.

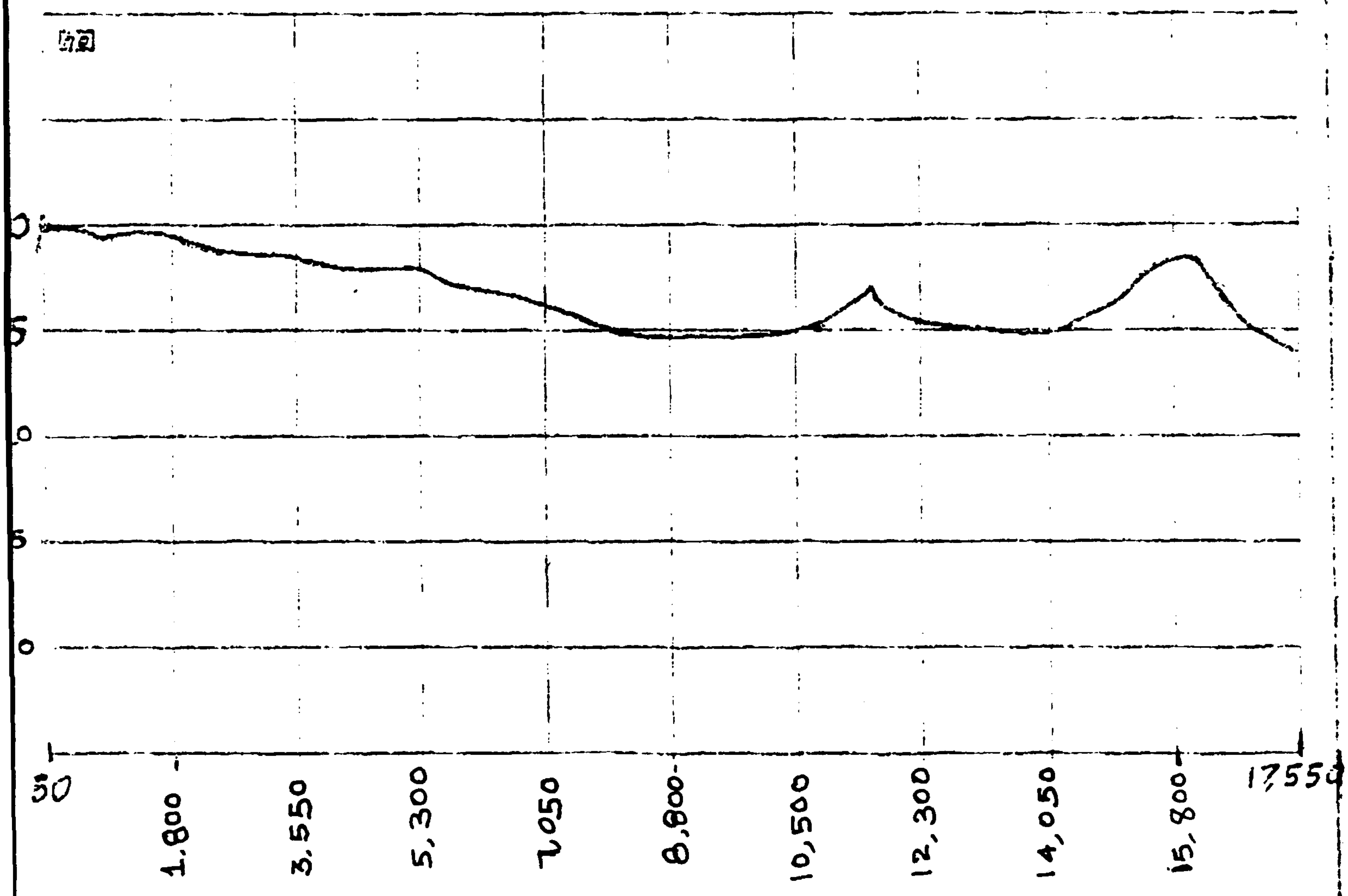

Figure 4. Attenuation measurements of a paint. 10 gms of 10% Hypalon, 10 gms of 6-9 μ iron powder.

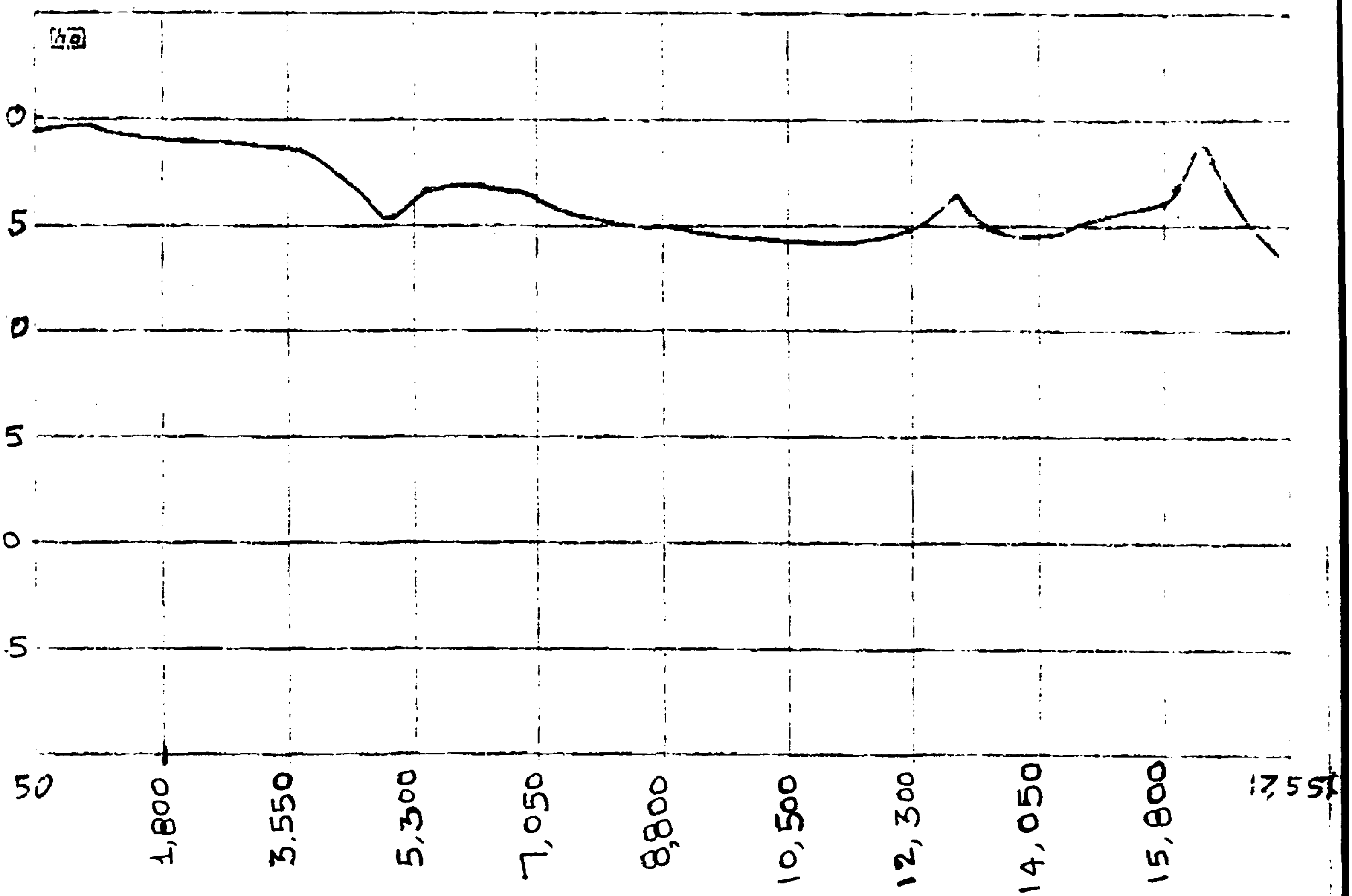

Figure 5. Attenuation measurements of a paint. 10 gms of Hypalon, 3 gms of iron powder and 5 gms of lithium ferrite.

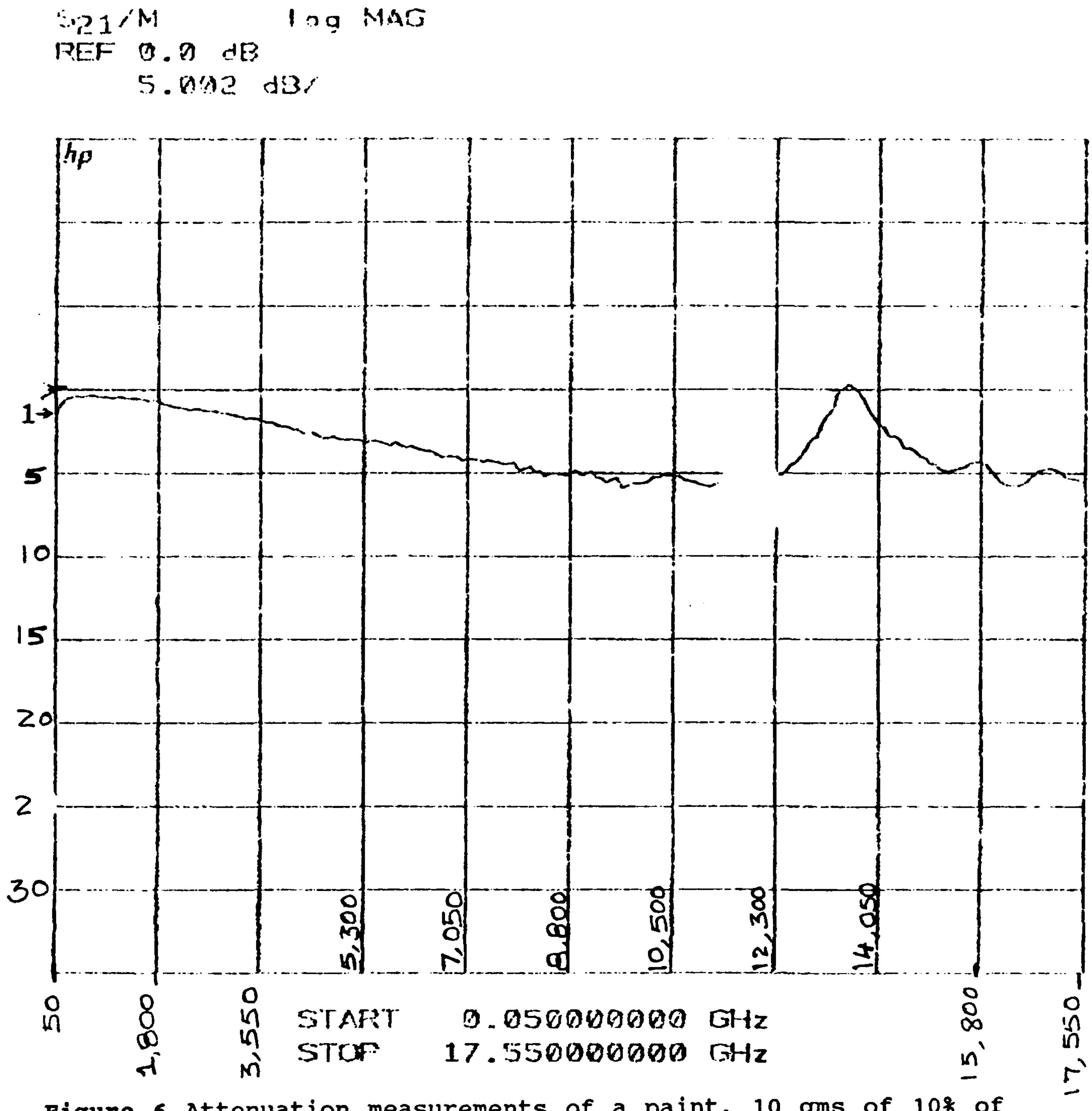

Figure 6 Attenuation measurements of a paint. 10 gms of 10% of Hypalon, 5 gms of nickel zinc ferrite.

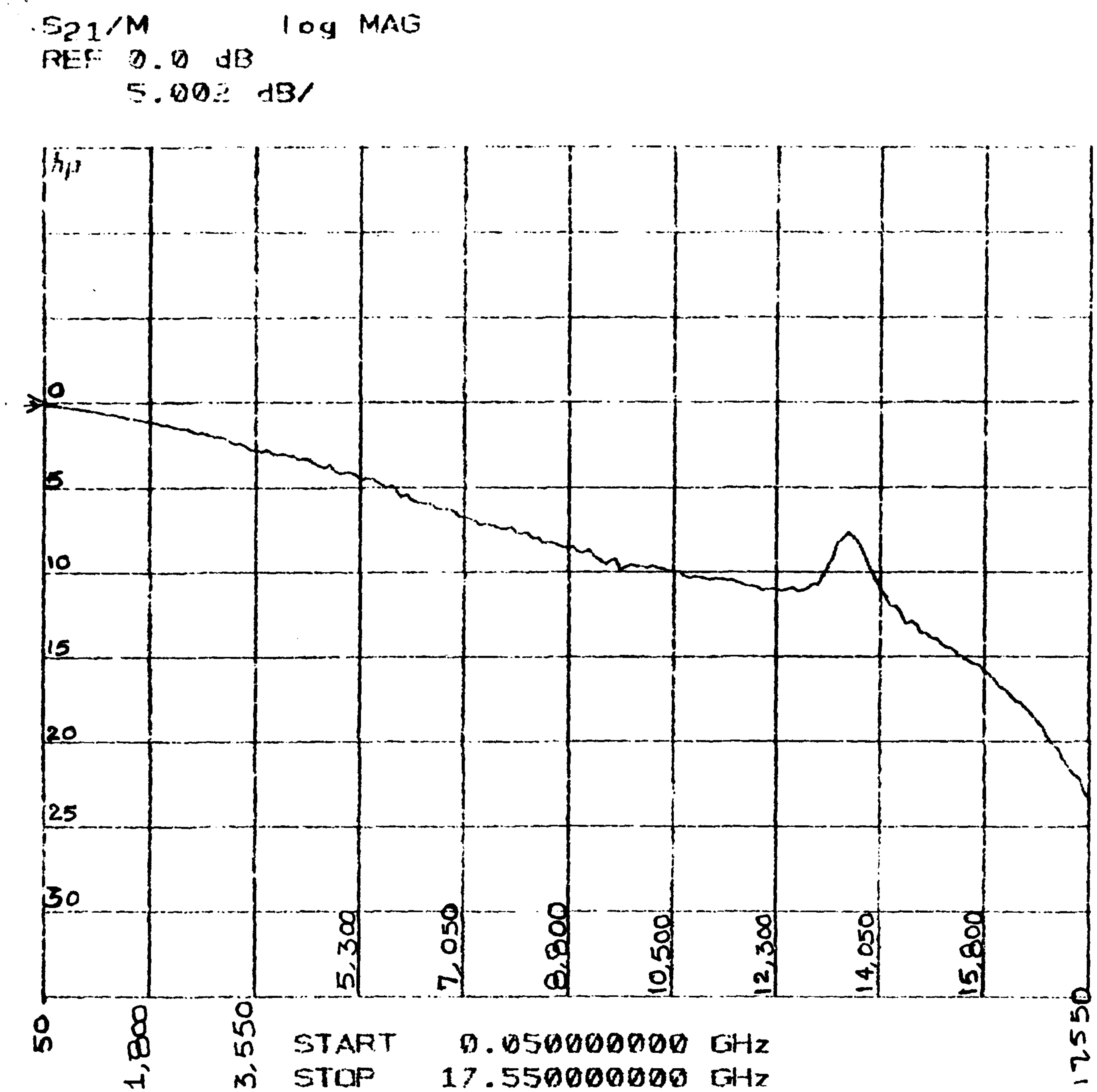

Figure 7. Attenuation measurement of a paint. 10 gms of 10% Hypalon, 3 gms of iron powder, 3 gms of nickel powder and 3 gms of nickel zinc ferrite.